Renewable and Sustainable Energy Reviews 41 (2015) 277–283

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Potential use of landfill biogas in urban bus fleet in the Brazilian states: A review

W.C. Nadaletti [a], P.A. Cremonez [b,*], S.N.M. de Souza [b], R.A. Bariccatti [b], P. Belli Filho [a], D. Secco [b]

[a] UFSC - Federal University of Santa Catarina, Post-graduation Program, PhD Course of Environmental Engineering, Trinity District CTC, Florianópolis, Santa Catarina, 88040-900, Brazil
[b] UNIOESTE - Western Paraná State University - Post-graduation Program, Master Course of Energy in Agriculture, Street University, 2069, School District, Cascavel, Paraná, 85819-130, Brazil

ARTICLE INFO

Article history:
Received 13 February 2014
Received in revised form
26 July 2014
Accepted 16 August 2014

Keywords:
Biogas
Renewable energy
Biofuel
Urban bus

ABSTRACT

The biogas is obtained from organic materials in decomposition. Among its components in energy terms, the methane is the most important, in particular for the combustion process in internal combustion engines. This article discusses the potential use of biogas produced from municipal solid wastes (MSW) of sanitary landfills from all Brazilian states to supply the current urban bus transportation fleet with great environmental, economic and social benefits. According to this study, Brazil generates about 16,131,857 N $m^{3/}$h of biogas, which could supply the actual bus fleet, estimated in 107,000 vehicles. The use of methane derived from sanitary landfills to substitute the mineral diesel guarantees the minimization of environmental impacts providing a significant reduction in the emission of greenhouse gases (GHG). Still from a socioeconomic point of view, the use of the potential energy of the sanitary landfills enables the biogas utilization for the urban transport sector, reducing fuel costs and decreasing the spread of many diseases related to the human respiratory system.

Contents

1. Introduction . . . 277
2. Composition of the Brazilian Urban Solid Waste (USW) . . . 278
3. The production of CH_4 and the individual potential of Brazilian states . . . 279
4. Methodology . . . 279
5. Brazilian highway bus fleet . . . 279
6. The diesel emissions: economic, environmental and social costs . . . 280
7. Conclusion . . . 282
Acknowledgments . . . 282
References . . . 282

1. Introduction

Nowadays, it is widely accepted that the heightened use of fossil fuels as a primary source of energy configure itself as unsustainable, due to its imminent scarcity and contribution to the environmental pollution [1].

Since the industrial revolution the demand for energy grows each year worldwide, particularly in developing countries. In Brazil, for the next 10 years, it is suggested an increase of 5.3% of energy per year, reaching 372 million TOE (Tons of Oil Equivalent) to the end of the decade [2].

In 2011, CO_2 in Brazil reached 395.8 $MtCO_2$, when the transport section was responsible for 48.5% of this total, followed by the industrial sector, with 24.9% [3]. These fuels, therefore, need to be replaced by renewable and clean energy sources in order to reduce the emissions of greenhouse gases and carbon dioxide [55].

* Corresponding author. Tel.: +55 44 9927 5099.
E-mail address: pa.cremonez@gmail.com (P.A. Cremonez).

http://dx.doi.org/10.1016/j.rser.2014.08.052
1364-0321/

Globally, the interest in biofuels is growing every day, being an alternative in what concerns to energy security, climate and poverty reduction [4,5].

According to the Ministry of Mines and Energy (Ministério de Minas e Energia – MME) [3], the predominance of fossil fuels in the Brazilian energy matrix is still significant and the division of domestic energy supply in the base year of 2011 showed a participation of 44.1% in respect to renewable energies, against 55.9% of non-renewable energy, being 37.8% of that derived from petroleum [6]. Thus, the adoption of different energy development models, focused on the use of biomass, has been widely exploited in the country. As we can see from the Brazilian's alcohol program, called ProÁlcool, launched in 1975, and from the current national program for production and use of biodiesel, called PNPB, which ones were presented as energy's successful policies. Only in 2009, the national investment in renewable energy was around US$ 7.4 billion [7].

In this scenario, the biofuels and the hydropower, in the national matrix, are sources that elevate the country as the second and the fourth largest producer in the world, respectively. However, from sustainability's point of view, although the small hydropower plants are considered sustainable, the environmental damages caused by the largest power plants – as in the most part of the Brazilian ones – hamper its characterization like renewable sources, in fact [8]. Furthermore, in issues related to hydropower plants, Brazil is vulnerable to prolonged droughts, as was observed in 2001 and 2002, when long interruptions of energy were cogitated.

Within this general overview on reduction of greenhouse gases emission and clean energy generation, the biogas production created from the anaerobic digestion of urban, livestock and other solid wastes constitutes a valuable bioenergy source with potential to partially relieve the world's dependence on fossil fuels, offering an integrated, competitive and environmentally sustainable solution. Among the sources of energy production, the biomass presents an elevated potential to a close future. It is considered as one of the main alternatives for the energy matrix diversification, providing a reduction in the fossil fuels dependence [9].

Nowadays, the biogas is produced around the world on a large scale; such production occurs from the anaerobic digestion of the organic matter present in the waste water, sewage sludge, manure and other wastes, and its potential use as a clean and environmentally correct energy source has been emphasized in the last years [10,11]. The large volume of wastes coming from agriculture and livestock exploration, domestic sewage and treatment stations show a high pollutant load that imposes the application of solutions that allow the reduction in damage caused to the environment, spending the minimum possible of energy in the whole process [12].

From the point of view of solid waste treatment, the use of anaerobic processes is widely employed, once the anaerobic microorganisms degrade the organic matter, generating biogas and biofertilizers as final products [13,14]. The biogas produced from anaerobic is composed of 40–70% of methane, being the remainder composed of carbon dioxide, hydrogen, sulfides and some trace of other gases [15]. However, the utilization of biogas in Brazil aiming the electric power is still incipient, with only 42 MW of installed capacity and 20 MW under construction [16].

The current Brazilian bus fleet is composed of 107,000 vehicles [17]. Experiences with the biogas use in urban vehicles has been related since the eighties and nineties, such as the Modesto city one, in the state of California, United States [18]. In Brazil, the first experiences have begun in Campinas' city, involving the sanitary landfill of Santa Barbara [19] and in Sao Paulo, where urban traffic buses were adapted to consume biogas [20]. Since then, many experiences have been tested around the world, with the use of alternative fuels to supplement or replace the conventional fuels, like ethanol, biodiesel, biogas, among others [21–23].

In the case of the Vehicular Natural Gas, the tests began in the eighties after the adoption of the National Plan of Natural Gas (Plano Nacional de Gás Natural - PLANGAS), by the Ministry of Mines and Energy, as a governmental strategy in response to the price oil shock in the seventies, followed by the high international interest rates [24]. Natal was the first Brazilian city to have urban buses running with this gas, in a program sponsored by the City Hall and Petrobras, which involved the test of a Brazilian Mercedes Benz's bus and a diesel-gas converted bus. The program began in 1983 and in 1991 reached the largest fleet of buses propelled by gas in the country, which means 15% of the urban city fleet at the time [25].

From this scenario, the present study proposed a survey about the amount of biogas generated in each Brazilian state per year and about its potential use in urban traffic bus fleet, as a replacement for the diesel oil, a fossil fuel and highly contaminant, therefore, environmentally unviable.

2. Composition of the Brazilian Urban Solid Waste (USW)

Several factors influence the composition of USW in the cities, varying according to the number of inhabitants, educational level of the population, purchasing power, level of family income, manners and customs, climate conditions, and the increase of industrialized foods.

The USW is composed of degradable organic matter (waste of animal or vegetables) and non-degradable matter as plastics, glass, leather, metal and others [26]. Table 1 shows the composition of USW in Brazil.

The main components of the wastes found in Brazil are organics, plastics and paper, which contribute to 78% of the waste (by weight). The potential of energy production depends on the amount and quality of the USW. From Table 1 it can be seen that the Brazilian USW has a good percentage of organics, which further will produce biogas. On the other hand, the organics have 60% of moisture, reducing the low heating value (LHV), variable that is important in the incineration process [28]. From Table 2 it is

Table 1
Composition of USW in Brazil.

Material	Participation (%)	Quantity (t/year)
Metals	2.9	1,640,294
Paper	13.1	7,409,603
Plastic	13.5	7,635,851
Glass	2.4	1,357,484
Organic matter	51.4	29,072,794
Others	16.7	9,445,830
Total	**100**	**56,561,856**

Source: Abrelpe [27].

Table 2
Amount of the urban solid wastes collected per region in Brazil.

Regions	2011-USW total (t/day)	2012-USW total (t/day)
North	11,360	11,585
Northeast	39,092	40,021
Midwest	14,449	14,788
Southeast	93,911	95,142
South	19,183	19,752
Brazil	**177,995**	**181,288**

Source: Abrelpe [27].

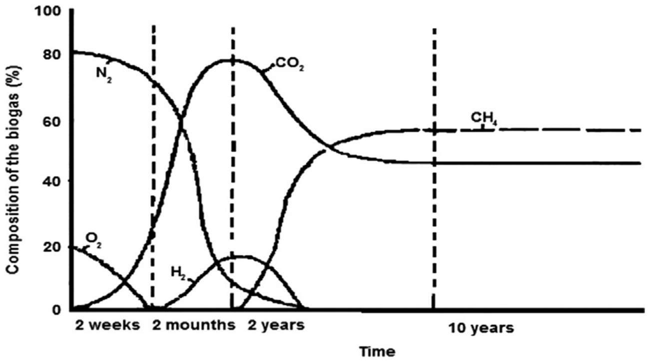

Fig. 1. Production of biogas components with the time.
Source: LIMA, [19].

possible to note the amount of USW collected per region and the whole country. Again, the Southeast region is responsible for the largest amount of USW generated, followed by northeastern and south regions of Brazil.

3. The production of CH_4 and the individual potential of Brazilian states

From Fig. 1, it is possible to see the profile of the biogas production in the sanitary landfills over the time, presenting a stationary production of methane (CH_4) after the tenth year of operation, an interesting fact if related to its useful life, that is about 15–20 years. Although there are known chemical reactions that describe the anaerobic digestion process in landfills as a function of determinate parameters, like temperature, humidity, composition of discarded wastes and the diversity of substrates for microbiological degradation [29,30,31], in practice, the quantity of percolated liquid processed in the digesters is the main control parameter to the biogas production; in other words, its production increase occurs when there are high rates in the digestion process [32].

The daily volume of CH_4, obtained from the landfills of a determinate city, can be estimated as the product of the city's population, the daily per capita production of urban waste, the participation of organic material between the wastes, the volume of CH_4 generated per unit of weight of organic material and the methane's recuperation relation on the sanitary landfills. Data related to the population of each Brazilian state were obtained from ABRELPE and IBGE, for the base year of 2012, as well as the statistics related to the total solid wastes produced and the fraction of organic matter.

4. Methodology

The calculation steps and the values for production of methane from USW of these states, object of this study, are shown in Table 3. The method adopted in the research was based on the literature reviews about the quantification and qualification of the solid wastes, the generation and utilization of biogas as energy source, the population data and about the amount of urban solid wastes generated by each Brazilian state.

The method used for this study was based on the methodology recommended by the Intergovernmental Panel on Climate Change – IPCC [33]. The reference adopted was the edition “Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual/Workbook”, in the chapters related to the item “Wastes”, contained in the Brazilian inventory of anthropogenic emissions of greenhouse gases, held by the Brazilian Company of Technology in Environmental Sanitation (Companhia de Tecnologia de Saneamento Ambiental – CETESB), and the Ministry of Science and Technology (Ministério da Ciência e Tecnologia – MCT), and from the “Guideline 2006” [34]. The method used in this study followed an equation, involving the estimated amount of degradable organic carbon existing in the waste, calculating this way the quantity of methane that can be produced by a specific amount of deposited waste, through the following equation:

$$\text{Emission of } CH_4(\text{Gg/year}) = [\text{Popurb} \times \text{RSD} \times \text{RSDf}]$$
$$\times \text{FCM} \times \text{COD} \times \text{CODf} \times \text{F} \times 16/12\text{–R}) \times (1-\text{OX}),$$

Gg=Gigagram (1 Gigagram or Gg=109 grams); Popurb=Urban Population=86,656 habitants; RSD=Rate of generation of Domestic Solid Waste per habitant per year=0,5 kg/hab day=500 g/hab day=500×10^{-9} Gg/hab day=5×10^{-7} Gg/hab day; RSDf=Fraction of Domestic Solid Waste that is Deposited in Disposition Places=0.6; FCM=Correction factor for methane [Dimensionless fraction]=1; COD=Degradable Organic Carbon in Domestic Solid Waste [Dimensionless fraction]=COD (fraction)=0.4A+0.17B+0.15C+0.30D=0.16; CODf=DOC's fraction that really degrades [Dimensionless fraction]=0.77; F=Fraction of CH_4 in landfill gas=0.4; 16/12=Conversion rate of carbon into methane [Dimensionless fraction]; R=Amount of recovered methane [$GgCH_4$/year]=ignoble (not emitted, burned in the flare); OX=Oxidation Factor [Dimensionless fraction]=ignoble (There is not formation of CO_2 before combustion of methane in landfill);

PD=(Y (hab.$\times10^{-7}$ (Gg/day hab)$\times$365 (days/year)$\times$0.6]$\times$1.0$\times$0.16$\times$0.77$\times$0.4$\times$16/12; PD/Density of methane (0.716 kg/N m^3)=Volume of CH_4=PD/0.716=870,781 N m^3/year (dividing by 365 days and 24 h)=Z N m^3/h.

According to Azevedo [35], the calorific power of biogas varies from 17 to 34 MJ/kg (superior) to 15–34 MJ/kg (lower). The calorific power of some gases, including the methane, is shown in Table 4. If compared to other fuels the feasibility of the methane use as fuel, mainly in cars is evident.

However, for the application of the biogas in diesel cycle engines, it is necessary that the same be purified in order to reach the specifications of the Natural Gas, and finally be used in vehicles adapted to this fuel. At the end of 2005, there were more than 5 million vehicles adapted to the use of GNV in the world.

The amount of buses and trucks powered with natural gas is also increasing, totaling 210,000 heavy vehicles (140,000 trucks and 70,000 buses), especially in European countries, which shows that the vehicle configuration is not a problem for the use of biogas as a fuel [36]. In practice, this means that CO_2, H_2S, NH_3, particulate matter (PM) and water (and sometimes other components-trace) need to be removed, so that the resultant gas for vehicular use has methane content higher than 95% in volume. In each country, different specifications for vehicular use of biogas and the natural gas are applied.

In the European Union, biogas is the fuel obtained from biomass more widespread in the last years, mainly due to the regulatory measures developed with the aim of expanding its production in the several economic sectors involved [37].

5. Brazilian highway bus fleet

According to data from the National Association of Urban Transportation – NTU [17], the highway bus fleet is composed of 107,000 vehicles, with 40 million of passengers transported per day. Also according to the Association, these vehicles perform a route of 204 million of kilometers per month only in the capitals. Data from DENATRAN [38] (the National Traffic Department) show

Table 3
Gas methane production per Brazilian states.

State	Urban population 2012 (hab.)	RSU collected per hab. (kg/hab./day)	RSU collected (t/day)	Production of organic matter (t/day)	CH_4 prod. (m^3/day)	RSU 10^{-7} Gg/hab/day	Production of CH_4 (Gg ano^{-1})	Tons CH_4/ano	Vol CH_4 N m^3/ano	Vol CH_4 N m^3/h
Acre	550,547	0.859	473	243.12	1864.44	9E−08	0.68052	680.52	950,447	108.50
Amapá	626,826	0.881	552	283.73	2177.22	9E−08	0.79465	794.65	1,109,848	126.70
Amazonas	2,842,261	1.16	3297	1694.66	12,998.20	1E−07	4.74434	4744.34	6,626,168	756.41
Pará	5,343,274	0.941	5028	2584.39	19,822.50	9E−08	7.2352	7235.20	1E+07	1153.54
Rondônia	1,168,326	0.853	996	511.94	3928.93	9E−08	1.43406	1434.06	2,002,874	228.64
Roraima	359,226	0.869	312	160.37	1230.69	9E−08	0.4492	449.20	627,376	71.62
Tocantins	1,119,773	0.828	927	476.48	3655.28	8E−08	1.33418	1334.18	1,863,378	212.71
Alagoas	2,336,035	0.984	2299	1181.69	9062.23	1E−07	3.30771	3307.71	4,619,713	527.36
Bahia	10,241,377	1.05	10,754	5527.56	42,394.40	1E−07	15.474	15,474.00	2.2E+07	2467.10
Ceará	6,471,917	1.098	7106	3652.48	28,015.30	1E−07	10.2256	10,225.60	1.4E+07	1630.32
Maranhão	4,238,099	0.958	4061	2087.35	16,006.50	1E−07	5.84238	5842.38	8,159,755	931.48
Paraíba	2,880,280	0.956	2754	1415.56	10,855.60	1E−07	3.96229	3962.29	5,533,923	631.73
Pernambuco	7,159,178	0.994	7118	3658.65	28,055.00	1E−07	10.2401	10,240.10	1.4E+07	1632.62
Piauí	2,081,271	0.966	2011	1033.65	7926.23	1E−07	2.89307	2893.07	4,040,604	461.26
RN	514,779	0.967	2432	1250.05	1962.49	1E-07	0.71631	716.31	1,000,433	114.21
Sergipe	1,554,858	0.956	1486	763.80	5860.16	1E−07	2.13896	2138.96	2,987,371	341.04
DF	2,558,923	1.599	4091	2102.77	16,131.20	2E−07	5.88788	5887.88	8,223,301	938.73
Goiás	5,572,288	1.05	5852	3007.93	23,066.60	1E−07	8.41931	8419.31	1.2E+07	1342.33
MT	2,552,936	1.024	2613	1343.08	10,306.30	1E−07	3.76178	3761.78	5,253,883	599.76
MS	2,145,497	1.04	2232	1147.25	8796.74	1E−07	3.21081	3210.81	4,484,374	511.92
Espírito S.	2,987,670	0.908	2714	1395.00	10,695.00	9E−08	3.90366	3903.66	5,452,040	622.38
MG	16,953,796	0.944	16,011	8229.65	63,095.70	9E−08	23.0299	23,029.90	3.2E+07	3671.77
RJ	15,694,169	1.303	20,450	10,511.30	80,620.10	1E−07	29.4263	29,426.30	4.1E+07	4691.58
São Paulo	40,177,103	1.393	55,967	28,767.00	220,643	1E−07	80.5347	80,534.70	1.1E+08	12840
Paraná	9,035,534	0.86	7771	3994.29	30,634.70	9E−08	11.1816	11,181.60	1.6E+07	1782.74
RS	175,397	0.832	7635	3924.39	575.32	8E−08	0.20999	209.99	293,282	33.478
SC	5,372,117	0.809	4346	2233.84	17,133.80	8E−08	6.25385	6253.85	8,734,429	997.08
Brazil	**63,713,417**	**1107**	**181,288**	**93,182**	**2.8E+08**	**0.0001**	**101,492**	**1E+08**	**1.4E+11**	**1.6E+07**

Table 4
Values for superior and lower calorific power for different gases.

Fuel	PCS e PCI (MJ/kg)
Methane	**55.5–50.0**
Natural gas	50.0–45.0
Gasoline	47.3–44.0
Light diesel	44.8–42.5
Heavy diesel	43.8–41.4
Refinery gas	42.3–38.6
Ethanol	29.7–26.9
Charcoal	29.7–n/d
Methanol	22.7–20.0

Source: Azevedo [35].

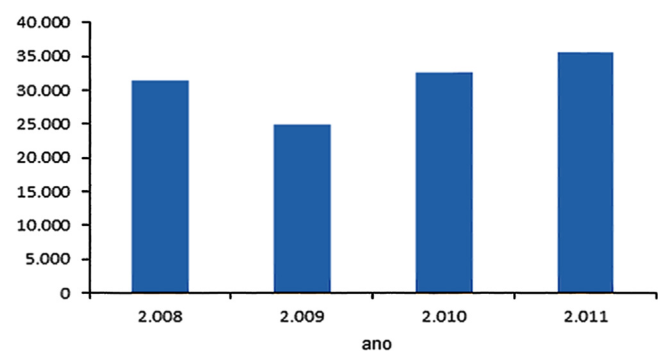

Fig. 2. Production of bus bodies in Brazil.
Source: NTU [17].

that in September 2012, there were 824,875 buses, minibuses and chassis platform in Brazil.

The urban and road transport of passengers is an essential public service in the country, according to the National Agency of Terrestrial Transportation (Agência Nacional de Transportes Terrestres – ANTT) [39]. Only the regular road transport was responsible for 71% of the displacements in 2008 according to the Statistical Yearbook of ANTT [40]. Also according to the same agency, with respect to legislation and inspection, the passenger transport is divided into collective, intercity, interstate and international transports.

Public service fleets offer an attractive option for the introduction of new renewable fuels in large scale, which allows the reduction of greenhouse gases emitted into the atmosphere, mainly by the increase of these vehicles in the country. Fig. 2 shows the total of bus bodies produced by Brazilian industries in the last four years, according to the National Association of Automobile Manufacturers [41]. From these data, it is possible to observe the increase in the production of collective vehicles in recent years.

Fig. 3 shows the last survey of ANTT concerning the bus fleet operating in Brazilian major cities in 2007. From this, the potential use of biogas in large scale in the bus fleet is evident, mainly in Sao Paulo's city, which is also the largest producer of USW, facilitating the fuel's availability in the center of direct use, allowing saving with biogas logistics.

6. The diesel emissions: economic, environmental and social costs

The fossil fuels, under combustion process, both in the diesel or gasoline engines or in the mixed fuels ones, release substances such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen

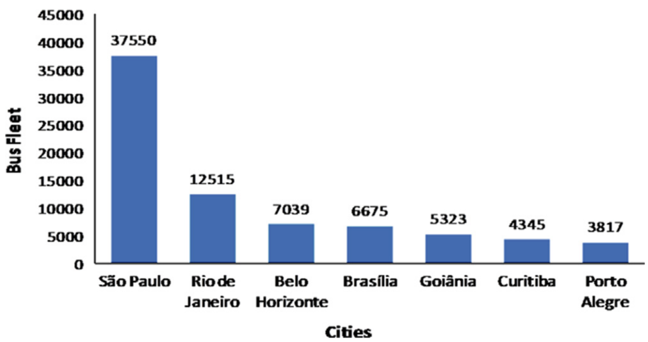

Fig. 3. Bus fleet in the largest Brazilian cities.
Source: ANTT [40].

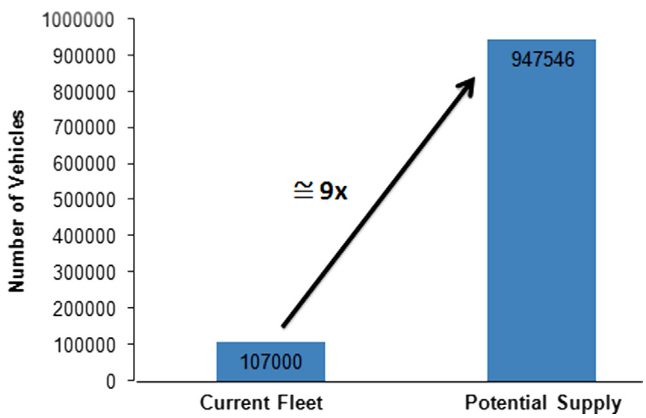

Fig. 4. Relation between the current and the potential supply of collective public transport vehicles by the introduction of biogas as a fuel.

oxides ($NO_x = NO + NO_2$), sulfur dioxide (SO_2), polycyclic aromatic hydrocarbons (PAHs), particulate matter (PM), among others. These substances, especially when in excess in the environment, can cause injuries to the human health, global warming, acid rain, vegetation and material structures damages, with significant economic losses [42].

The ANP resolution number 32 of 2007 limits the sulfur content in diesel fuel for use in motor vehicles at 50 ppm (parts per million) and is called Diesel S50. According to Adeodato [43], after 2013 the diesel will have just 10 ppm of sulfur with the reduction program.

He et al. [44] reveals that there are many studies about gas emissions, like CO, NO_x, THC (Total Hydrocarbons), derived from diesel, biodiesel and from their blends, but there is not too much about the particulate emissions, both in the form of organic carbon and in the form of elemental carbon.

These particles contribute to the formation of PAHs in urban areas and are closely related to respiratory diseases.

Thus, the main advantages of substituting diesel for methane gas are:

- reduction of petroleum and diesel import;
- contribution to the large use of methane gas and diversification of the energy matrix;
- reduction of atmospheric emissions in cities.

The fuel substitution in the buses implies the reduction of diesel consumption, which is currently responsible for 40% of the total petroleum consumed in the country [45]. However, in the sanitary landfills, biogas produced by anaerobic digestion of organic waste is usually piped and burned in torches or flares, and its energy released is not used; it just avoids the emission of methane gas into the atmosphere.

Considering a standard model of bus, with supply ability of 8500 cm^3 of diesel oil, a Detroit Diesel motor S50, according to Santarelli [46], in a study considering 300 days/year of operation for each urban bus, with 160 km/day or 48.000 km/year, the lifetime of each one is approximately 12 years. The same author considers the average consumption of 1.45 km/L of fuel in these vehicles. If we consider the period of useful life aforementioned, the annual consumption and mileage, the diesel consumption over 12 years reaches 394,520.54 l. Taking into consideration the economic perspectives, according to data from the National Agency of Petroleum, Natural Gas and Biofuels [47], the diesel's liter price in Sao Paulo was R$ 2.49 in August 31 2013. This represents a fuel cost of R$ 985.906,84 per vehicle. Expanding this value to the actual Brazilian road fleet of 107,000 buses, the fuel consumption to the same time period would be around R$ 105,492,031,880.00 without judging the inflation index.

On the other hand, assuming that the autonomy of a bus is around 400 km per day, the daily consumption for this diesel vehicle is 160 l, which is equivalent to 5824 MJ. A Volvo bus has an autonomy of 400 km running with 1055 m^3 and 136.2 kg cylinders of compressed natural gas [32]. If the compressed natural gas has an energy content of 47.5 MJ/kg [48], a Volvo bus consumes an energy equivalent to 6469.5 MJ per day. Analyzing the data above, it was estimated that biogas average daily consumption is about 6.147 MJ per bus or 295.5 m^3 of biogas per bus. Accordingly, the amount of biogas produced per day in the Brazilian states sanitary landfills shows itself enough to supply 947,546 buses (Fig. 4) of the same characteristics, being this quantity much higher than the current fleet available in the country.

Only a complete fuel replacement of the Sao Paulo's bus fleet for biogas could prevent the emission of 4.3 t per day of carbon derived from fossil fuels in the atmosphere. When the environmental variables are in discussion (which ones, undoubtedly, have the greatest importance in this study), we realize that they are connected to the pollutant emissions in high population density areas. According to CETESB [49], the main agents present in the atmosphere pollution are, among others, CO and PM. Furthermore, according to the NAAQS – National Ambient Air Quality Standards – of EPA – Environmental Protection Agency [50], carbon monoxide (CO) is transported to the lung and tends to form carboxyhemoglobin (COHb), enabling a framework for hypoxia caused by the elevated concentration of this component. CO effects on the human body include vision problems, reduced cognitive ability, reduced manual skills, difficulty in perform complex tasks, breathing problems and even death. The same Agency also claims that the PM can increase respiratory symptoms; mortality in patients with cardiovascular and pulmonary diseases; neoplasm; worsening of asthma attacks; and decrease the lung function in children.

The existence of comorbidities, such as diabetes type 2 and its association with exposure to air pollution, propitiate an increase of visits to hospital emergency departments, and consequently a bigger number of cardiovascular diseases related to the basic problem [51].

The effects of air pollution were also demonstrated in what concerns the tear film instability and in the symptomatology of ocular discomfort [52]. Reproductive function has also been the target of studies that have proven the harmful effects on fertility and fetal health, showing that the exposure to air pollutants is associated with low birth weight, retarded intrauterine growth, prematurity, neonatal death and male/female fertility reduction [53].

According to the systematic review by Olmo [54] an interrelationship between the health area is necessary, through

epidemiological studies and the adoption of public policy measures to minimize the effects of air pollution in large urban centers.

Considering the exposition above, the possibility of substitution of biogas in buses can make the big Brazilian cities more sustainable and drastically reduce the costs related with hospital admissions and with the public health in general. On the other hand, there are technical and market limitations. The form of gaseous biogas to be used at normal pressure and temperature requires its pressure in the cylinders, and for this reason, the costs are higher. In addition, there is a lack of technological innovation to convert landfill gas into biogas in Brazil. The feasibility depends on financial incentives and policies by the government.

7. Conclusion

The viability in the use of landfill gas to replace diesel oil enables the minimization of the environmental impacts and ensures a significant reduction in the greenhouse gases emissions (methane). According to this study, Brazil generates about 16,131,857 N m^{3}/h of biogas, which could supply the actual bus fleet, estimated in 107,000 vehicles.

From a socioeconomic perspective, a landfill enables the use of biogas for the urban transport sector, reducing fuel costs, and decreasing the spread of human respiratory systems diseases.

Acknowledgments

This research has received financial support of CAPES (Coordination for the Improvement of Higher Level).

References

[1] Khan SA, Rashmi, Hussain MZ, Prasad S, Banerjee UC. Prospects of biodiesel production from microalgae in India. Renew Sust Energy Rev 2009;13(9):2361–72.
[2] Tolmasquim MT. Perspectivas e Planejamento do Setor energético no Brasil. Estud. av. 2012;26:74.
[3] MME – Ministério das Minas e Energia. Balanço Energético Nacional (BEN). Brasília: MME/EPE. 2012. ⟨https://ben.epe.gov.br/downloads/Resultados_Pre_BEN_2012.pdf⟩ [August 2013].
[4] Charles M, Ryan R, Ryan N, Oloruntoba R. Public policy and biofuels: the way forward? Energy Policy 2007;35(11):5737–46.
[5] Doku A, Falco S. Biofuels in developing countries: are comparative advantages enough? Energy Policy 2012;44:101–17.
[6] Ferreira LL. (Master´s thesis). Flexibilidade na utilização de diesel ou biodiesel, uma abordagem utilizando a teoria de opções reais. Rio de Janeiro: Fundação Getulio Vargas; 2007; 54.
[7] Corporate clean energy investment trends in Brazil,China, India and South Africa. Londres: Carbon Disclosure Project. 2009. ⟨https://www.cdproject.net/CDPResults/Clean%20energy%20trends%20in%20emerging%20markets%20ENGLISH.pdf⟩ [ago/2013].
[8] Coleman G. The BRIC energy balance sheet: Brazil powering growth? Brasilinvest Banco de Negócios, 27 April 2012. 2012. ⟨http://www.brasilinvest.com.br/eng/pressroom/noticia_completa.php?id=32⟩ [ago/2013].
[9] Neto EDD, Alvarenga LH, et al. Implementação e Avaliação de um Biodigestor de Produção Descontínua. Revista eletrônica E-xacta 2010;3(2):36–43.
[10] Appels L, Baeyens J, Degrève J, Dewil R. Principles and potential of the anaerobic digestion of waste-activated sludge. Prog Energy Combust Sci 2008;34(6):755–81.
[11] Petersson A, Wellinger A. Biogas upgrading technologies - developments and innovations. IEA Bioenergy 2009:20.
[12] Pecora V. Implantação de uma unidade demonstrativa de geração de energia elétrica a partir do biogás do tratamento residencial de esgoto da USP - estudo de caso. (Master´s thesis in Engineering). Interunities Graduate Program in Energy (PIPGE) of the Institute of Electrotechnics and Energy (IEE) of the University of São Paulo. USP; 2006; 153 p.
[13] Lianhua L, Dong L, Yongming S, Longlong M, Zhenhong Y, Xiaoying K. Effect of temperature and solid concentration on anaerobic digestion of rice straw in South China. Int J Hydrog Energy 2010;35(13):7261–6.
[14] Nges IA, Liu J. Effects of solid retention time on anaerobic digestion of dewatered sewage sludge in mesophilic and thermophilic conditions. Renew Energy 2010;35(10):2200–6.
[15] Singh KJ, Sooch SS. Comparative study of economics of different models of family size biogas plants for state of Punjab, India. Energy Convers Manag 2004;45(9):1329–41.
[16] ANEEL. Banco de Informações de Geração. 2009. ⟨www.aneel.org.br⟩ [September 2013].
[17] NTU - Associação Nacional das Empresas de Transportes Urbanos. 2012. ⟨http://www.ntu.org.br/novo/Default.aspx?v=1232⟩ [September 2013].
[18] Henrich RA. Landfill and digester' gas purification by water extraction: a case study of a commercial system - Baltimore's back river wastewater treatment plant. In: Proceedings of the symposium on energy from biomass and wastes, Florida, USA; 1983, p. 877–906.
[19] Lima LMQ.The biodegradability method to determine the production of methane in the landfill of Santa Barbara, in the CiQ of campinas (in Portuguese). CPFL, Campinas; 1985.
[20] Machado FTHF A. Utilização do onibus a gás natural comprimido na frota de onibus urbanos como alternativa para a redução da poluição atmosférica na região metropolitana de São Paulo. IEE/University of São Paulo - USP, Biblioteca Digital USP; 1996; 176p (M.Sc. thesis).
[21] Ryan F, Caulfield B. Examining the benefits of using bio-CNG in urban bus operations. Transp Res Part D 1996;15(6):362–5.
[22] Sánchez JAG, Martinez JMK, Martín JL, Holgado MNF. Comparison of life cycle energy consumption and GHG emissions of natural gas, biodiesel and diesel buses of the Madrid transportation system. Energy 2012;47(5):174–98.
[23] Chollacoop N, Saisirirat P, Sukkasi S, Tongroon M, Fukuda T, Fukuda A, et al. Potential of greenhouse gas emission reduction in Thai road transport by ethanol bus technology. Appl Energy 2013;102:112–23.
[24] Nogueira SS. Uso do GNV em ônibusurbano para operar em linha comercial – Projeto piloto Gasbus. (Master thesis in Mechanical Engineering). Porto Alegre-RS: Faculdade de Engenharia da Universidade Federal do Rio Grande do Sul – UFRGS; 2006; 176p.
[25] Oliveira Filho AD. Substituição de Diesel por Gás Natural em ônibus do Transporte Público Urbano. (Master thesis in Energy). São Paulo-SP, Biblioteca Digital USP: Universidade de São Paulo – USP; 2006; 144p.
[26] Lino FA, Ismail KAR. Energy and environmental potential of solid waste in Brazil. Energy 2011;39(6):3496–502.
[27] Abrelpe – Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais. Panorama dos resíduos sólidos no Brasil. São Paulo, 2012; 186 p.
[28] Leme MMVLeme MMV. Avaliação da opções tecnológicas para geração de energia a partir de resíduos sólidos urbanos: estudo de caso. Thesis (Master in Energy Engineering), Universidade Federal de Itajubá – EFEI. 2010; 123p.
[29] Christensen TH, Kjeldsen P, Bjerg PL, Jensen DL, Baun A, Albrechtsen JB, et al. Biogeochemistry of landfill leachate plumes. ApplGeochem 2001;16(7):659–718.
[30] Bove R, Lunghi P. Electric power generation from landfill gas using traditional and innovative technologies. Energy Convers Manag 2006;47(11):1391–401.
[31] Sevimoglu O, Tansel B. Effect of persistent trace compounds in landfill gas on engine performance during energy recovery: a case study. Waste Manag 2013;33:74–80.
[32] Kuwahara N, Berni NMD, Bajay SV. Energy supply from municipal wastes: the potential of biogas – fuelled buses in Brazil. Renew Energy 1999;16(1):1000–3.
[33] Guidelines for national greenhouse inventories: reference manual, Vol. 3. IPCC –International panel on climate change; 1996.
[34] CETESB. Primeiro Inventário Brasileiro de Emissões Antrópicas de Gases de Efeito Estufa - Relatórios de Referência. Emissões de Metano no Tratamento e na Disposição de Resíduos. São Paulo, SP; 2006.
[35] Azevedo MH. Características, produção e utilização do biogás produzido a partir de resíduos orgânicos. (Thesis (Promec's Master), Universidade Federal do Rio Grande do Sul, Porto Alegre-RS. Repositório UFRGS; 2000.
[36] IEA. Renewables Information 2006. Paris, IEA. 2006. ⟨http://www.oecd-ilibrary.org/energy/renewables-information-2006_renew-2006-en⟩ [September 2013].
[37] Tricase C, Lombardi M. State of the art and prospects of Italian biogas production from animal sewage: technical-economic considerations. Renew Energy 2009;34(3):477–85.
[38] DENATRAN – Departamento Nacional de Trânsito; 2012. ⟨http://www.denatran.gov.br/⟩ [September 2013].
[39] ANTT – Agência Nacional de Transportes Terrestres; 2013. ⟨http://www.antt.gov.br/⟩ [September 2013].
[40] ANTT – Agência Nacional de Transportes Terrestres; 2008. ⟨http://www.antt.gov.br/⟩ [September/2013].
[41] ANFAVEA – Associação Nacional dos Fabricantes de Veículos Automotores; 2012. ⟨http://www.anfavea.com.br/⟩ [September 2013].
[42] Quintella CM, et al. Cadeia do biodiesel da bancada à indústria: umavisão geral com prospecção de tarefas e oportunidades para P&D&I. Quím Nova 2009;32(3):793–808.
[43] Adeodato S. Diesel mais limpo chega em 2013. Biodieselbr online agosto de 2010. ⟨http://www.biodieselbr.com/noticias/em-foco/diesel-mais-limpo-2013-160810.htm⟩[September 2011].
[44] Zhang J, He K, Shi X, Zhao Y. Comparison of particle emissions from an engine operating on biodiesel and petroleum diesel. Fuel 2011;90(6):2089–97.
[45] MME – Ministério de Minas e Energia. BNE – Balanço Energético Nacional. Governo Federal. 2004.
[46] Santarelli MGL. Carbon exergy tax: a thermo-economic method to increase the efficient use of exergy resources. Energy Policy 2004;32(3):413–27.

[47] ANP – Agencia Nacional de Petróleo, Gás Natural e Bicombustíveis. 2013. ⟨http://www.anp.gov.br/⟩ [September 2013].
[48] Fearghal R, Caulfield B. Examining the benefits of using bio-CNG in urban bus operation. Transp Res Part D 2010;15:362–5.
[49] CETESB – Governo de São Paulo. 2010. ⟨http://www.cetesb.sp.gov.br/⟩ [September 2013].
[50] U.S. Environmental Protection Agency. 2009. ⟨http://www.epa.gov/ttn/naaqs/standards/co/data/cosp1992.pdf⟩ [September 2013].
[51] Pereira Filho MA, Pereira LA, Arbex FF, Arbex M, Conceição GM, Santos UP, et al. Effect of air pollution on diabetes and cardiovascular diseases in São Paulo, Brazil. Braz J Med Biol Res 2008;41(6):526–32.
[52] Novaes P, Saldiva PH, Matsuda M, Macchione M, Rangel MP, Kara-José N, et al. The effects of chronic exposure to traffic derived air pollution on the ocular surface. Environ Res 2010;110(4):372–4.
[53] Veras MM, Caldini EG, Dolhnikoff M, Saldiva PH. Air pollution and effects on reproductive-system functions globally with particular emphasis on the Brazilian population. J Toxicol Environ Health B, Crit Rev 2010;13(1):1–15.
[54] Olmo NRS. Poluição atmosférica e exposição humana: a evolução científica epidemiológica e sua correlação com o ordenamento jurídico [thesis]. São Paulo: Faculdade de Medicina, Universidade de São Paulo; 2011.
[55] Amin S. Review on biofuel oil and gas production processes from microalgae. Energy Convers Manag 2009;50(7):1834–40.